

SENSITIVITY OF BUILDING ENERGY SIMULATION WITH  
BUILDING OCCUPANCY FOR A UNIVERSITY BUILDING

A Thesis

by

SHREYANS CHHAJED

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Chair of Committee,  
Committee Members,  
Head of Department,

John A. Bryant  
José L. Fernández-Solís  
Geoffrey Booth  
Joseph P. Horlen

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## ABSTRACT

Occupancy plays a major role in determining energy use of any building. It plays an even more crucial role in the case of a university classroom building. These buildings are typically loaded with highly variable occupancies that vary from very low during breaks to very high during peak daytime hours in the middle of the semester. This paper presents how an energy simulation model was built and validated and then used to explore the effect of occupancy for a classroom/studio building on the campus of Texas A&M University. The energy model for the building was created using the DOE-2 engine and validated with actual energy consumption data. As constructed building characteristics and occupancy loading data were used in the DOE-2 model. Parametric runs were then completed with the validated energy model for variations in occupancy number, occupancy schedules, etc. With the exception of extremely high occupancy, the results show that all variations in occupancy or schedule resulted in less than a 10% deviation from the actual building performance model. These results demonstrate that though it plays a role in the energy performance of this type of a classroom building, occupancy and occupant schedules do not have a major effect on annual energy performance. The results show that, during the design stage of a building life-cycle, building designers do not need very accurate estimates for the occupancy of the proposed building.

## DEDICATION

I would like to dedicate my thesis to my beloved family, my research committee and my friends, thank you for all of your support along the way.

## ACKNOWLEDGEMENTS

I would like to express my special appreciation and kindest gratitude to my committee chair, Dr. John A. Bryant, for being so supportive and providing me guidance throughout my research. I would like to thank my committee members, Dr. José Fernández-Solís and Dr. Geoffrey J. Booth, for their guidance and support. Without persistent support and feedbacks offered by my research committee, this thesis would not have been possible.

Thanks to my family and friends who support me all the time. It is their encouragement and support that helped me get this far. It is their consistent faith in me which empowers me to face all the challenges in my life.

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## 1. INTRODUCTION

Buildings account for 40% of the world's total primary energy consumption and are responsible for 24% of the world's CO<sub>2</sub> emissions. According to a report from the Intergovernmental Panel on Climate Change (IPCC), CO<sub>2</sub> emissions from buildings have doubled from four gigatons (Gt) per year to about eight Gt per year in the last three decades and are expected to reach up to 14 Gt per year in the next three decades mainly as the result of increasing energy consumption from developing countries [1]. By 2030, the share of emissions from buildings will reach one-third of the total world's CO<sub>2</sub> emissions.

The use of building energy simulation tools such as DOE-2, eQUEST, Energy Plus, and others have become the standard for predicting thermal loads and energy performance of new buildings. These tools are being used during the design phase to determine a building's energy performance beforehand and choose appropriate building systems and envelope components. It is well established that a better understanding of the energy performance of a building can be used as a means to reduce building energy consumption related emissions. Sozer [2] performed a study to analyze the impact of the building envelope on building energy performance and made an attempt to propose better building envelope and system designs to improve energy efficiencies. For this purpose, energy modeling software has been widely used by designers and engineers. Research focused on producing an optimum model for HVAC and its sensitivity analysis

produced relations between cost parameters, CO<sub>2</sub>, optimal power generation unit capacity and optimal cooling ratio [3].

In reality, energy modeling tools often use simplistic or default data inputs that do not represent actual building systems or occupancy. Discrepancies are often observed between predicted and actual energy performance, usually averaging around 30 percent and often can diverge by up to 100 percent [4]. According to a study by Virote and Neves-Silva (2012), occupants' behavior can have a significant impact on building energy performance. Every building is designed with several assumptions about how the building and its systems are going to be used, but these may differ as compared to those assumed by the designer. With increased building energy codes and standards and performance expectations, impact of occupant behavior on energy consumption will also increase and thus, better models that take into account occupant behavior and presence are inevitable[5]. There is a need to understand and interpret these differences in a better way to reduce the discrepancies between predicted and actual energy consumption of buildings.

## 2. PROBLEM STATEMENT

Energy modeling and simulation tools are routinely used in the design of new and existing buildings to predict and understand energy use trends in these buildings. Large discrepancies between simulation results and actual energy consumption have been documented, and the role of occupancy and occupancy scheduling is not well understood. Research is needed to demonstrate the impact made by these variables on the modeling results in a university classroom building.

### 3. LITERATURE REVIEW

Literature review is the basis of any research. Recent updates, and research going on in the interested area of research is provided by existing literature. The process of analyzing literature helps in identifying the gap between existing research in a given field and hence the problem to work on. Thereafter the researcher develops and implements their own idea to fill the gap.

To begin with the research, it is necessary to identify relevant database in the field of study. The databases used for the literature review of this research are ScienceDirect, Google Scholar and ProQuest.

As soon as the databases were determined, keywords were identified to perform a literature search. The literature review may need to change or be more specific with time that may change the keywords used. The research started with general keywords like building energy use, building occupancy, and energy simulation. To further narrow the research, terms such as ; institution building, sensitivity analysis, validation and parametric runs were used. The literature was organized using RefWorks by exporting the references once the relevant studies were found and cited in APA format. The following section details findings of the literature review.

One of the greatest barriers for increasing buildings' energy efficiency is limited knowledge of the factors that determine actual energy use patterns. Often, there is a remarkable difference observed between the designed and the actual total energy use in

buildings. The contributors to this gap are poorly understood and largely have more to do with the role of human behavior than the building design [6]. Integrating user impact with building performance through occupant-related behavior and presence patterns are important elements in any whole building energy simulation analysis. Occupants influence building energy consumption through a variety of physical activities, making changes to the building's indoor environment such as opening/closing window shades, adjusting thermostat controls, and engaging in work and leisure-related tasks conducted within the building.

Degelman [7] noted that the building's operational characteristics, implying occupant behavior, can have an even greater impact on building energy performance than the building's thermal envelope. However, much less work has been done on modeling building occupant behavior as compared to modeling building mechanical and electrical systems. The American Society of Civil Engineers Visualization, Information Modeling and Simulation technical committee stated that accurately modeling building occupant behavior is a challenge that demands attention [8]. Efforts have been devoted to the identification of the impacts of occupant behavior on building energy consumption. Various factors influence building energy consumption at the same time, leading to the lack of precision when identifying the individual effects of occupant behavior [9].

Blight and Coley [10] analyzed 100 passive unit terraced houses in the United Kingdom to perform sensitivity analysis of the effect of occupant behavior on these dwellings. The research successfully created representative models, which could be validated with

the measured data. The study generated several "rules of thumb" relating occupant behavior and energy use in these houses. Sonderegger [11] tried to analyze occupant dependent impacts on energy consumption in similar houses. The study found that 71% of the variations in energy consumption trends that were unexplained by traditional energy metrics were caused by occupant-related behaviors. Further research on residential buildings identified 27 influencing factors related to occupant's behavior and considered the fact that simulating all these factors can be very difficult and may consume a greater amount of work than what it's worth. It suggests balancing model accuracy with resources and time [12].

Energy consumption trends can even become abrupt due to casual occupant practices. Some studies and energy audits have been carried out where energy use in unoccupied hours was more than during occupied hours that seem to be counterintuitive. The work showed that more energy was used during non-working hours (56%) than during working hours (44%). This difference was attributed to the occupants' behavior of leaving lights and equipment on [13]. The literature points to various studies that have been carried out to show the impact of occupancy behavior on building energy consumption and also what difficulties these simulation tools face due to these discrepancies between predicted and actual energy use patterns. Similar to the current research, the study focused on a typical cellular office building. For a set of 10 representative set, 144 profiles were produced using different combinations of occupancy patterns, lighting and blinds control and heat gain patterns of appliances. The results were then analyzed with respect to heating, cooling and lighting loads to compare

simulated energy performance with actual performance and a significant impact of occupant behavior was found [14].

According to a study of a given building, high variations in energy use can be observed due to occupants' actions. Conventional design methodologies do not consider occupant behavior and hence undervalues energy demand [15]. Kwok and Lee [16] did an assessment of impacts of occupancy loads on cooling loads and how these can help improve simulation predictions. They found that the simulation of the cooling load is significantly impacted by occupancy data and that the simulation accuracy is improved with better occupancy data. There have been research on analyzing high sensitivity parameters in building simulation models. Roles and practices of occupants that can help improve building's energy performance have also been identified [3]. Research to quantify the impact of different parameters in increased energy consumption for an office building was carried out using the DOE-2 simulation model. The study showed a strong correlation between tenant energy use pattern and the measured energy consumption. The tenant's light and equipment use pattern resulted in 56% of total energy use. Unanticipated tenant energy use contributed to 64% of the two-fold increase from predicted to actual energy use. The remaining 36% increase was mainly observed as a result of HVAC schedules, thermostat settings, equipment performance, conduction heat transfer coefficient and outdoor-air intake [17]. A similar study was carried out for a campus building, but it was mainly focused on HVAC and system performance. The predictions for the integrated model were found to be within  $\pm 15\%$  for the majority of the time and potential options for saving energy use were identified. The research also

identified the need of consistent data recording and measurement in order to perform a good validation process [18]. The actual impact on the observed differences due only to occupancy remains largely unknown with many factors driving the energy consumption because of occupant levels and schedules.



## 4. RESEARCH BACKGROUND

### 4.1 Research Objective

The objective of the research is to determine the impact of occupancy and occupancy schedule on energy use for an institutional classroom building. A building energy model (DOE-2) will be used to generate a simulation using as-built design input for the subject building. The annual energy performance model can then be validated with actual electrical and thermal energy data for the building. Further parametric studies will be run to investigate occupant loading and occupancy scheduling impact on energy performance for the subject building.

### 4.2 Research Hypothesis

A validated building energy simulation model will reflect large differences in the annual building energy consumption related to building occupancy for a classroom building.

### 4.3 Research Assumptions

The assumptions of this research are listed below:

- i. No major HVAC equipment failure/repair occurred during the year of study
- ii. Occupancy in the building was assumed to be constant as per given schedules rather than being dynamic
- iii. Factors apart from occupancy behaviors that drive energy consumption trends are presumed to behave in a similar fashion throughout the year and no abrupt/dynamic behavior is taken into account

- iv. Other system and/or building specifications which are not known are considered to be constant and since the simulation is comparative, do not need to be determined
- v. Values in the energy use data resulting from some metering errors were interpolated using values before and after the missing/out-of-range value
- vi. Some months of cooling/heating load data were abruptly found to have high/low values and hence were adjusted using data from previous year data and use of a modification factor.

## 5. RESEARCH METHODOLOGY

### 5.1 Gathering and Organizing Data

Before creating the model all required input data were gathered. These data included information such as weather, building systems, building material, building location and orientation, occupancy, mechanical systems, estimated lighting and plug loads, and actual energy use data. The data were collected, then organized and modified when required, in such a fashion so that it could be used directly as DOE-2 model input values. These are described in the following section.

#### 5.1.1 Building envelope and systems

The first step was to collect required data such as location and type of building HVAC systems and construction. The subject building is Langford Building C located on the campus of Texas A&M University (TAMU) in College Station, Texas. It is a typical four story university building with classrooms, architecture studios, computer labs, and office spaces and is aligned approximately 30° West of North with a gross area of about 58,600 ft<sup>2</sup>. The building has two buildings that project shade that are the Langford Building A (South) and Building B (West). Figure 1 shows the location and orientation of Langford building C as displayed in Google Maps. Windows cover almost 50% of the wall area on the North and South sides of the building. Langford Building C is concrete construction that includes an air gap in the walls. Glazing is single pane windows

throughout the building. Figure 2 shows the front (North) elevation of Langford Building C.



*Figure 1. Langford Building C (Black Star) on the Campus of Texas A&M University in College Station, Texas, as shown in a Grapic Map Capture from Ggoogle Maps.*



*Figure 2. Front (North) Elevation of Langford Building C at Texas A&M University, College Station, Texas.*

The building HVAC systems are multi-zone (MZ) type with constant volume air handlers. Mostly, T8-32W fluorescent lights are used throughout the building. Lighting loads were found to average about  $1.2 \text{ W/ft}^2$ . Unlike many other buildings on the campus, there are no automatic lighting sensors in this building and so most of the lights remain switched on throughout the day. Many of the other buildings on the Texas A&M campus have been retrofitted with occupancy sensors for the lighting systems. Equipment and plug loads together average around  $1.3 \text{ W/ft}^2$ . A major part of the equipment load results from a computer lab on each floor and a computer visualization lab on the fourth floor. Outside ventilation air (OA) is fixed for the first three floors of the building. The energy management system automatically modulates the OA for the 4th floor MZ AHUs. The OA volume was measured for each MZ with a hot-wire anemometer and found to be about 0.45 air changes per hour. The total supply air

delivered by each MZ AHU was also measured and found to be approximately 1.3 CFM/ft<sup>2</sup> for each unit on each floor. Observations taken with the anemometer are summarized in Table 1. There is an underground mechanical room which receives hot water, chilled water, and electrical power from the university central power plant.

*Table 1. Supply Air Volume CFM/ft<sup>2</sup> for the MultiZone Air Handling Units in Langford Building C at Texas A&M University, College Station, Texas.*

<b>MZ AHU</b>	<b>CFM</b>	<b>CFM/ft<sup>2</sup></b>
1	13,611	0.93
2	13,238	0.75
3	18,000	1.22
4	32,716	2.23
<b>Total</b>	<b>77,565</b>	<b>1.3 (average)</b>

#### 5.1.2 Occupancy data

After gathering the basic envelope information on the building, actual occupancy data were gathered. As occupancy plays an important role in energy use of the building and university buildings are highly loaded, an attempt to gather and then model occupancy data as accurately as possible was made. Raw data were obtained from a university online database and provided by the Texas A&M University Measurement and Research Services. The data included scheduled classes in the Langford C building and the number of students registered for the respective classes. The data were reorganized into

hourly bins covering one physical year of 8,760 hours. The scheduling of classes at Texas A&M follows the traditional (semester) meeting days of Monday/Wednesday/Friday (MWF) or Tuesday/Thursday (TTR). An average occupancy loading for Langford C for a fall semester MWF and TTR is shown in Figure 3. Similar data were generated for summer and spring semesters. Typical Wednesday schedules for Spring'12, Summer'12, and Fall'12 are shown in Figures 4 – 6.

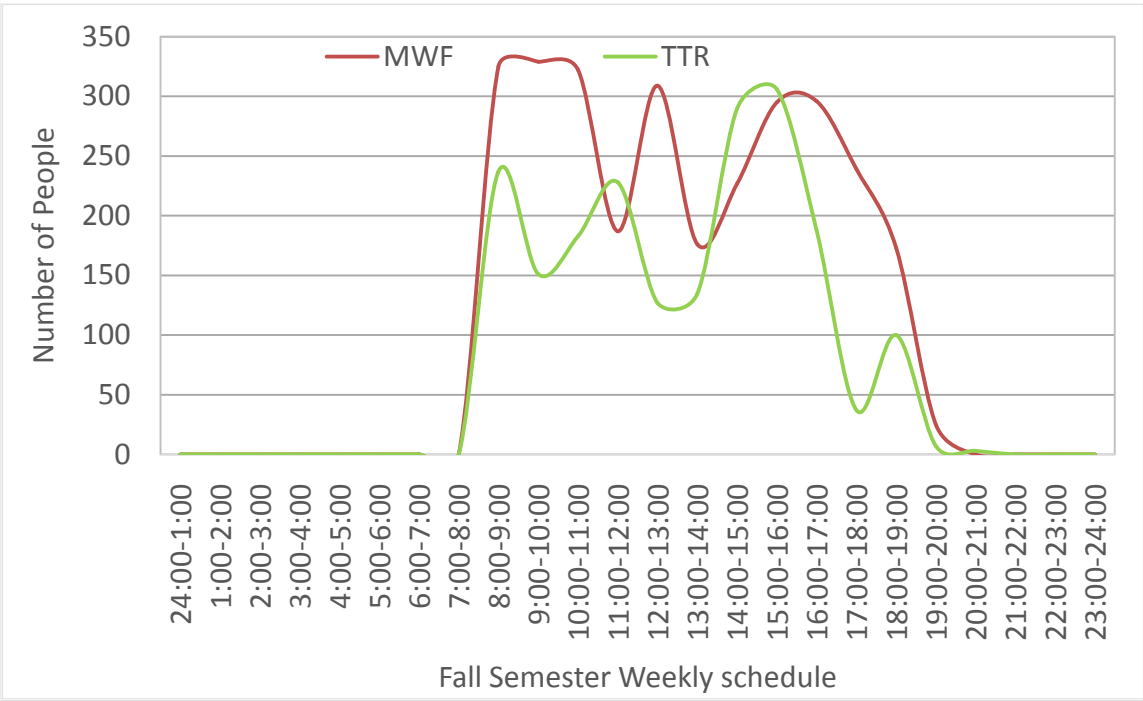


Figure 3. Fall, 2012 Weekly Occupancy Loading for Langford Building C.

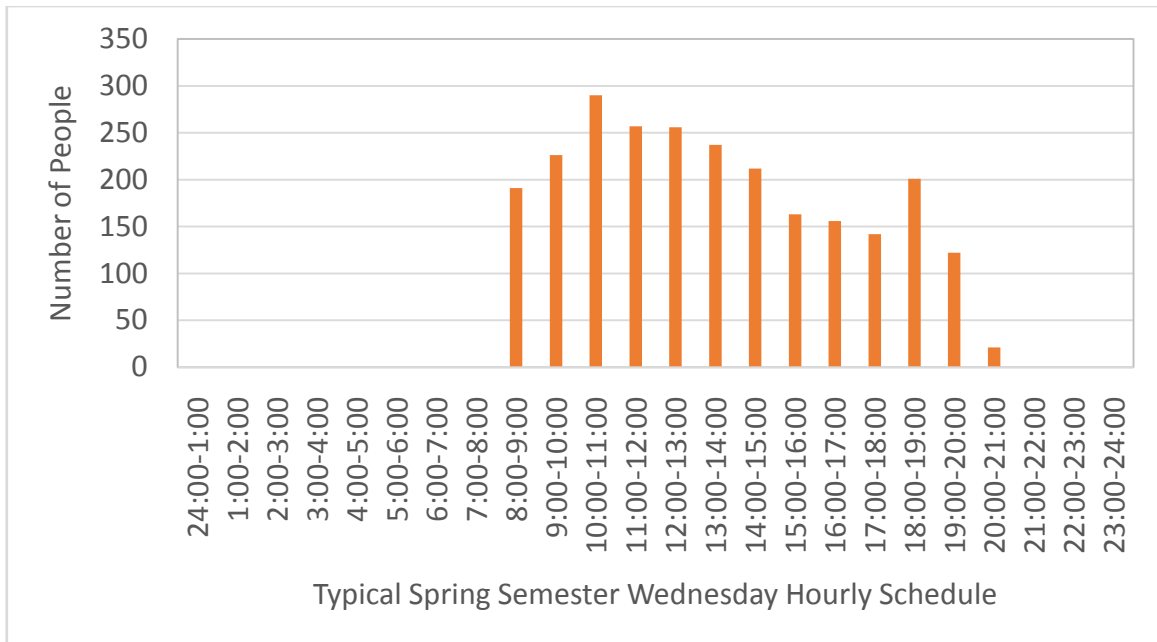


Figure 4. Spring 2012 Occupancy for Langford Building C.

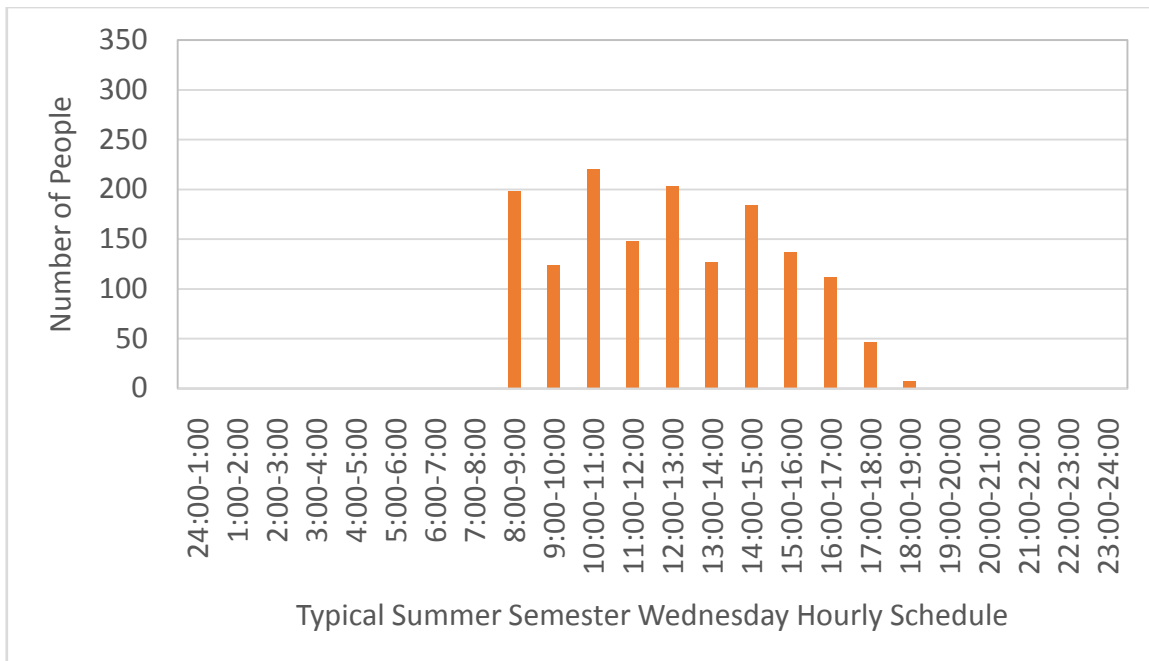
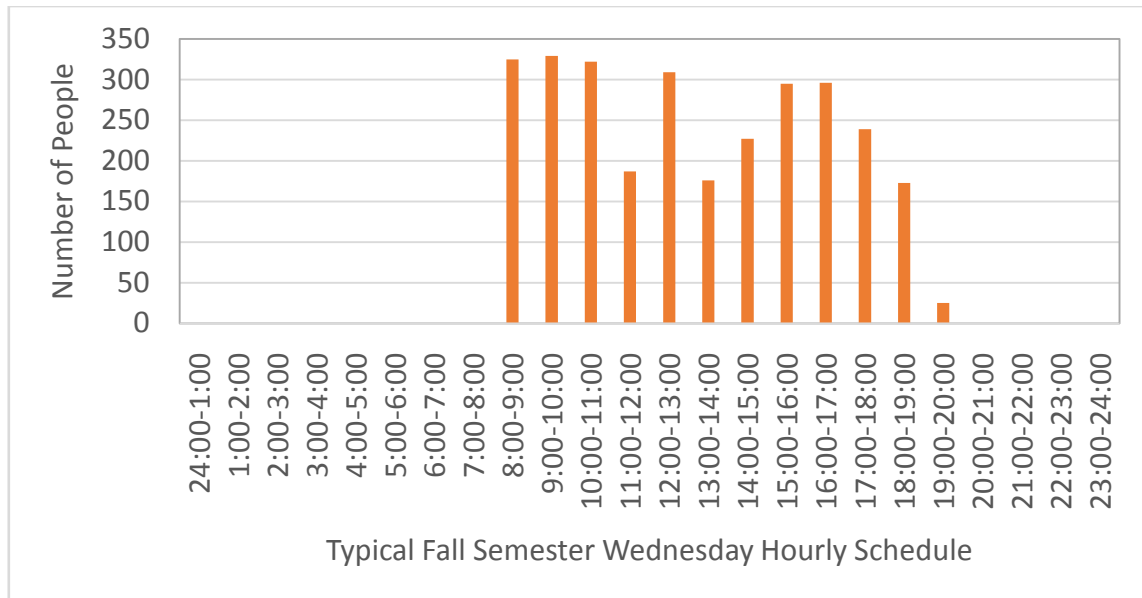


Figure 5. Summer 2012 Occupancy for Langford Building C.





*Figure 6. Fall 2012 Occupancy for Langford Building C*

These data were used as input occupancy values in the DOE-2 model. Occupancy on weekends was assumed to vary between 5% and 15% of the average weekday occupancy depending on time of day.

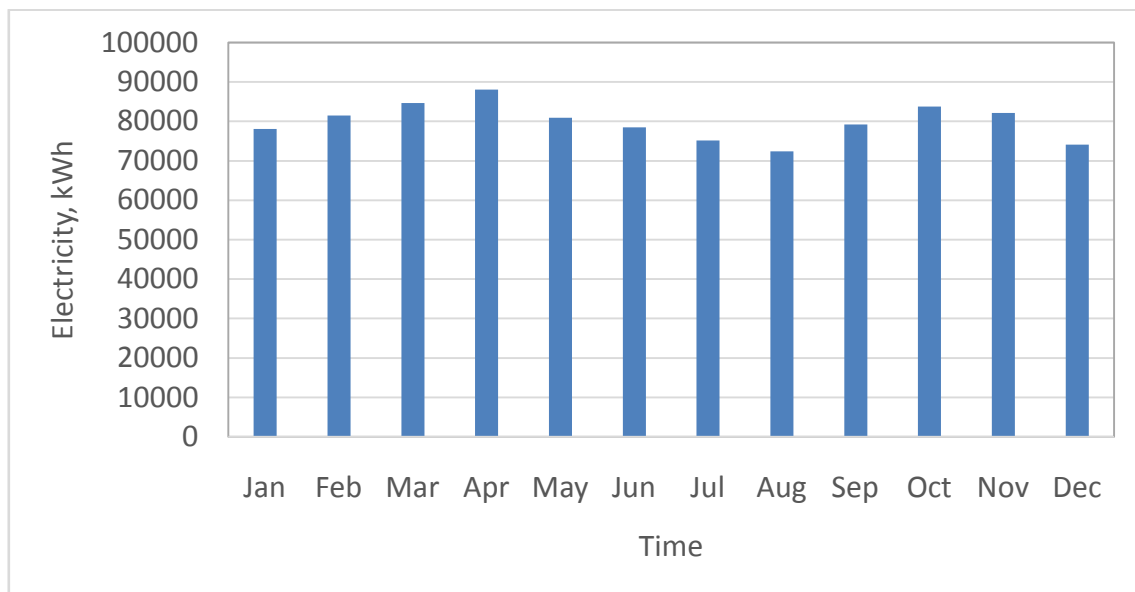
### 5.1.3 Energy use data

To validate the model, actual energy consumption data including thermal and electrical energy for Langford Building C were needed. These data for 2011 and 2012 were provided by the Utilities and Energy Services department of TAMU. These raw data were adjusted for weather and operating differences to result in a single energy consumption data set. Simulations were conducted using actual weather data for the two years and any differences in the DOE-2 model because of the weather effects resulted in a correction factor that was applied to the average of the actual consumption data.

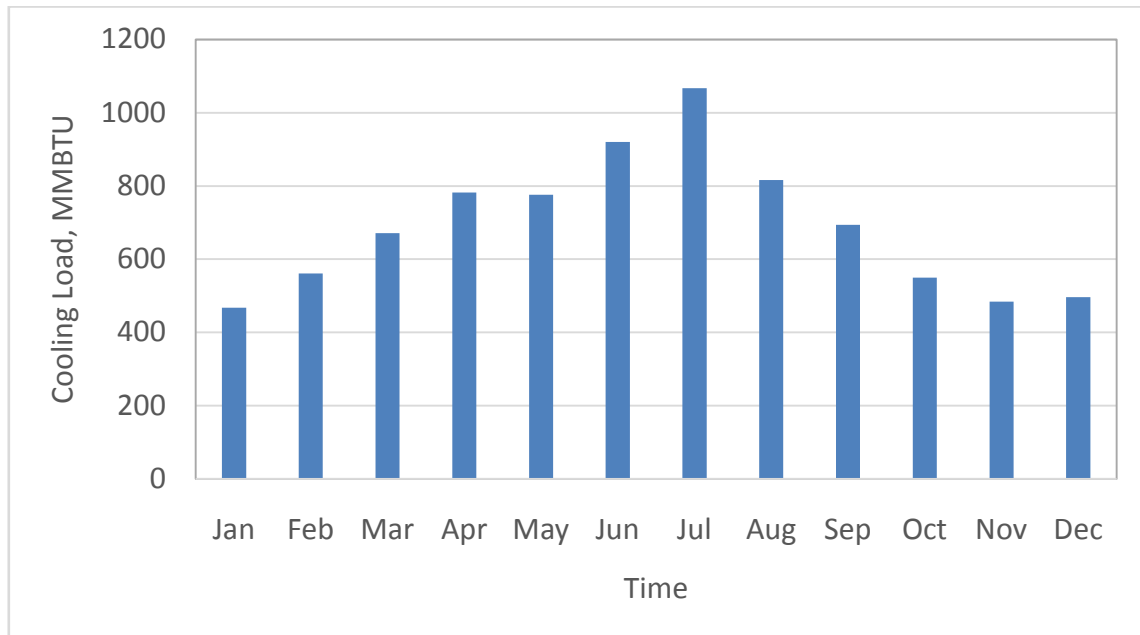
Sample modification factor calculations are shown in Table 2. Adjusted energy consumption values for Langford Building C for the year 2012 are as shown in Figures 7–9.

*Table 2. Modification Factor Calculations Used to Adjust Energy Use Data for Langford Building C.*

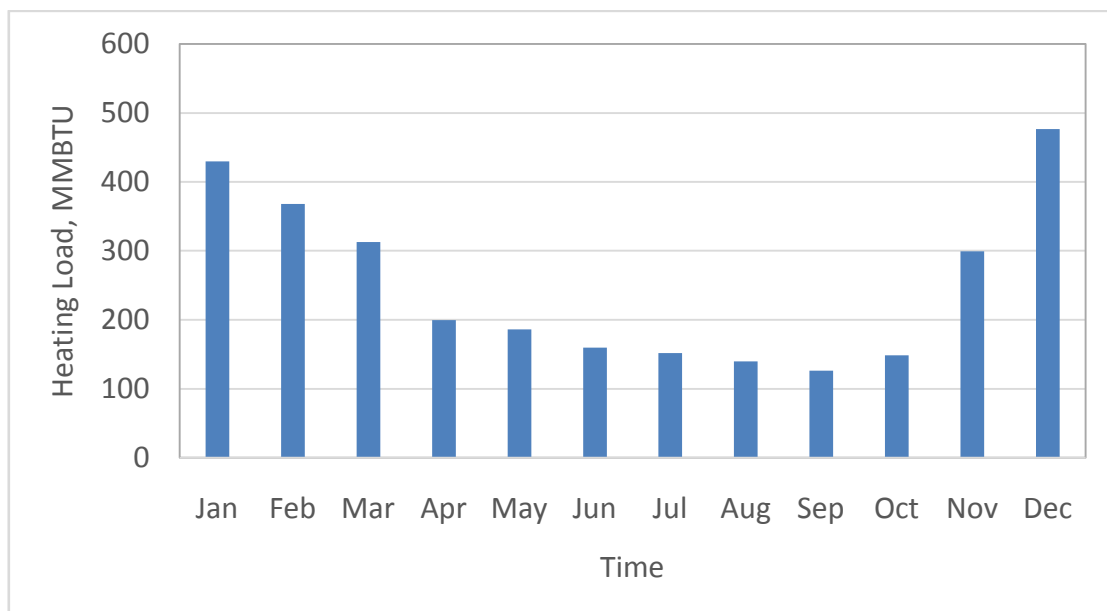
Cooling Load, MMBTU	Jan	Feb	Mar	Apr	May
Simulation 2012	464	360	611	784	932
Simulation 2011	485	372	635	815	962
Modification Factor	0.96	0.97	0.96	0.96	0.97



*Figure 7. Adjusted Annual Electric Data for Langford Building C.*



*Figure 8. Adjusted Annual Cooling Load for Langford Building C.*



*Figure 9. Adjusted Annual Heating Load for Langford Building C.*

## 5.2 Creating and Validating Model

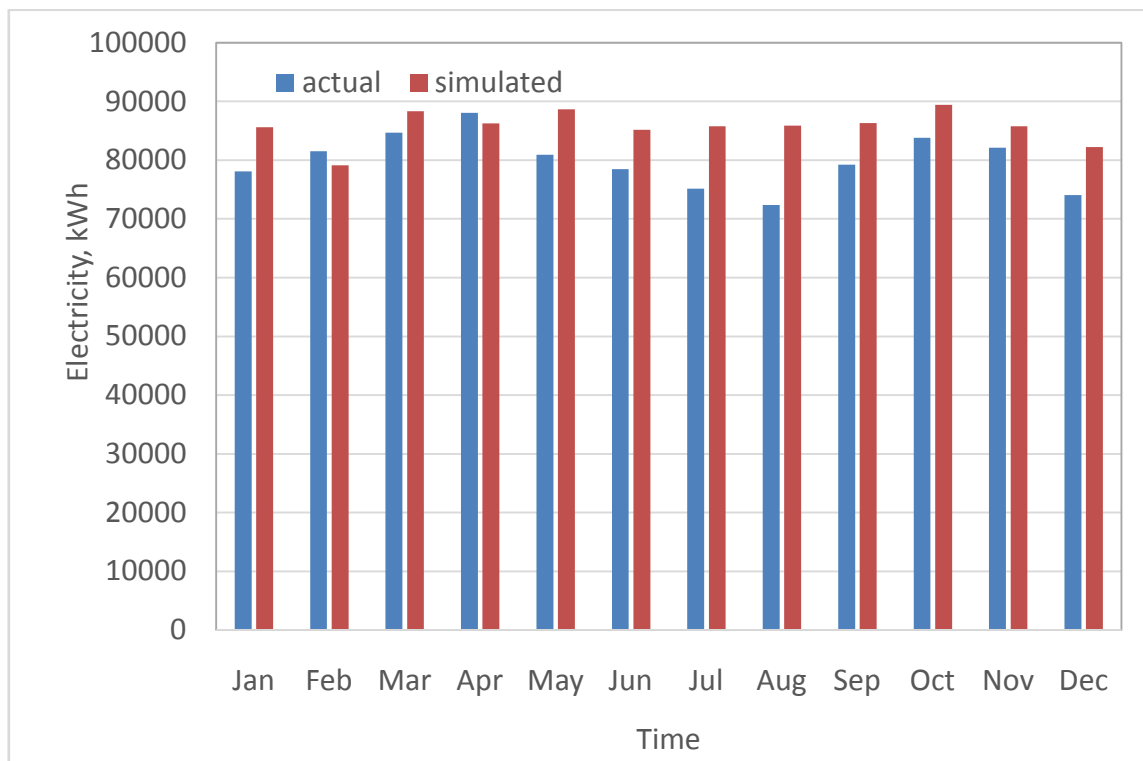
Once all the required information were gathered, a DOE-2 model for the Langford C was created. The use of DOE-2 defaults were minimized by detailing the model with actual building parameters including, but not limited to, building systems and materials, building envelope, weather conditions, occupancy loads, lighting and plug loads, supply and design temperatures for hot water and chilled water, and various schedules for occupancy, equipment, and lighting loads. As the model was completed, the simulation results were compared with the actual energy data in order to validate the model. The model was assumed to be valid once the simulated energy use data was within  $\pm 10\%$  of the actual energy consumption data. Table 3 shows some of the input data for DOE-2 model.

*Table 3. Sample of DOE-2 Model Inputs for Langford Building C.*

<b>Parametric Set</b>	<b>Occupancy/heat gain(BTU/person)</b>	<b>Light - w/ft<sup>2</sup></b>	<b>Equipment - w/ ft<sup>2</sup></b>	<b>Outside Air Changes/hr</b>	<b>CFM /ft<sup>2</sup></b>	<b>Occupancy type</b>
1	350/400	1.2	1.3	0.45	1.3	Variable occupancy
2	350/400	1.2	1.3	0.45	1.3	Constant occupancy
3	1150/400	1.2	1.3	0.45	1.3	Variable occupancy

### 5.3 Conduct Parametric Runs

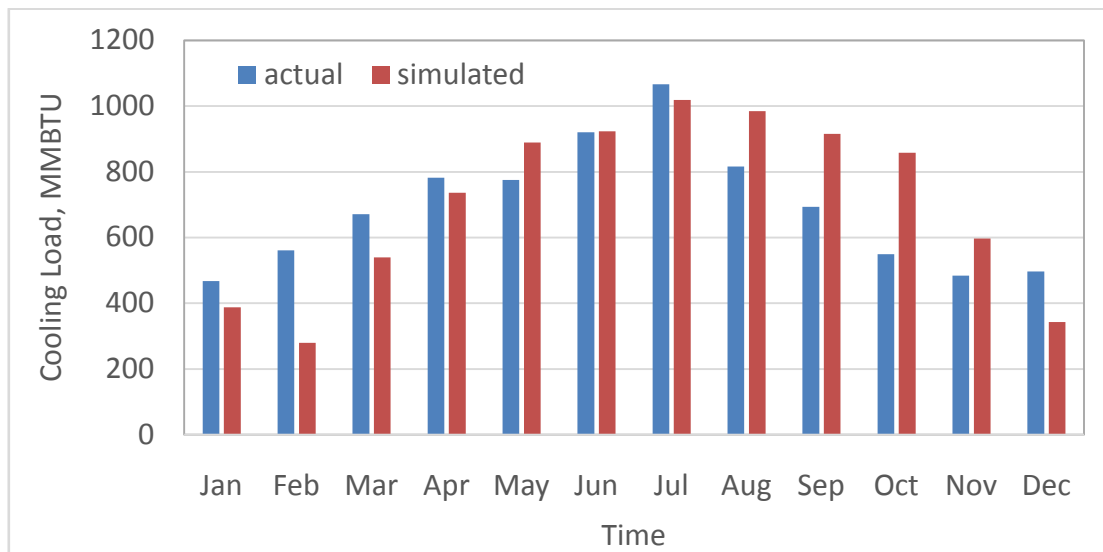
After validating the model, various parametric runs were performed to understand the impact of occupancy loading and results were then analyzed. Base electric, heating and cooling loads were compared to actual loads on a monthly basis as shown in Figures 10 – 12. Various parametric runs were carried out to understand the behavior of the models and their sensitivity with occupancy.



*Figure 10. Actual vs. Simulated Electrical Energy Use for Langford Building C.*

The parametric runs were based on actual, variable, constant, and National Fire Protection Association standards for occupancy loading in a university building. These cases were simulated and the results compared to actual energy consumption for the Langford C building. An energy use index was calculated and is shown in Table 4.

Simulation Run 1 used the actual building variable occupancy as supplied from the registration records at Texas A&M University. Simulation 2 assumed a constant occupancy of 350 throughout the school day for the whole year. In simulation 3, an occupancy load of 1,150 was used to analyze the sensitivity of the simulation tool with a very high building occupancy. Each of these first parametric models revealed a very low, less than 10%, impact of occupancy loading on building energy use. Further simulations were carried out to explore this result and these are described in Table 5.



*Figure 11. Actual vs. Simulated Cooling Energy Use for Langford Building C.*

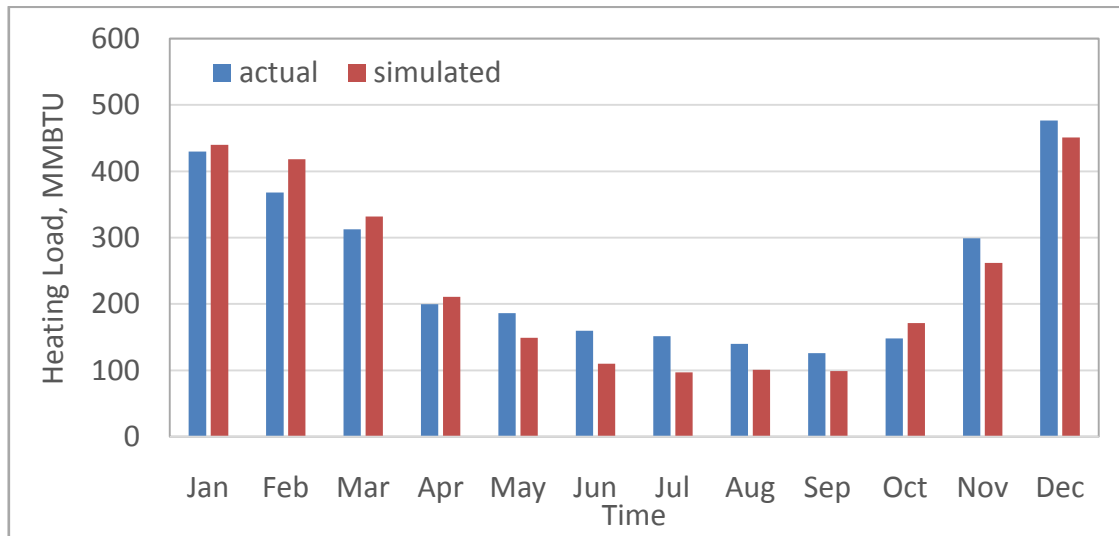


Figure 12. Actual vs. Simulated Heating Energy Use for Langford Building C.

Table 4. Energy Use Data Resulting from Parametric DOE-2 Simulation Models.

	Electric load, KWH	Heating load, MMBTU	Cooling load, MMBTU	Electric, kBTU/ft <sup>2</sup>	Heating, kBTU/ft <sup>2</sup>	Cooling, kBTU/ft <sup>2</sup>	EUI, kBTU/ft <sup>2</sup>
<b>Actual</b>	<b>958,619</b>	<b>2,998</b>	<b>8,286</b>	<b>56</b>	<b>51</b>	<b>141</b>	<b>248</b>
<b>Sim1</b>	1,029,832	2,851	8,663	60	49	148	256
<b>Sim2</b>	1,030,954	2,966	8,637	60	51	147	258
<b>Sim3</b>	1,051,033	3,109	9,999	61	53	170	284

*Table 5. Description of DOE-2 Parametric Models with Changes in Occupancy Loading.*

Simulation 1	Actual variable occupancy
Simulation 2	Actual constant occupancy
Simulation 3	NFPA guideline occupancy loading
Simulation 4	Null occupancy
Simulation 5	50% reduced occupancy
Simulation 6	25% reduced occupancy
Simulation 7	25% increased occupancy
Simulation 8	50% increased occupancy



## 6. RESULTS AND DISCUSSIONS

The base model was found to agree with the actual electrical and thermal energy consumption for the building to within  $\pm 10\%$  when compared on an annual basis. The 10% figure was set by the researchers as an indication that the model was accurately modeling the subject building. As is common in building energy modeling, the finer the time step, the more difficult it is to exactly match actual energy consumption data. Armed with a validated model, additional parametric modeling runs were conducted with the DOE-2 engine to study the sensitivity of the annual model to varying occupancy in this building. Three modeling cases were completed: the base case using actual data from the Langford classroom building, a scenario using an occupancy level similar to actual numbers but kept constant throughout the week, and a case with a fixed maximum design occupancy load allowed as per the National Fire Protection Association (NFPA) guidelines.

Figure 13 shows the three DOE-2.1 models compared to the actual building energy data. The models with different occupancies did not appear to deviate by a substantial amount. To quantify these differences, a percent deviation from actual data was calculated for each model. Figure 14 represents these difference between a given model and the actual energy consumption data for the building on an annual basis. The largest difference is shown to be about a 21% increase in the cooling load under the high occupancy level that would result from using the NFPA guideline. This increase in the cooling load

would be expected because of the additional sensible and latent load from the large number of people in the building and the increased requirement for outside ventilation air. For all other cases, the increase or decrease in the model compared to actual is less than 10%. This would indicate that the model is relatively insensitive to the number of occupants in this building and insensitive to the scheduling of those occupants in the building.

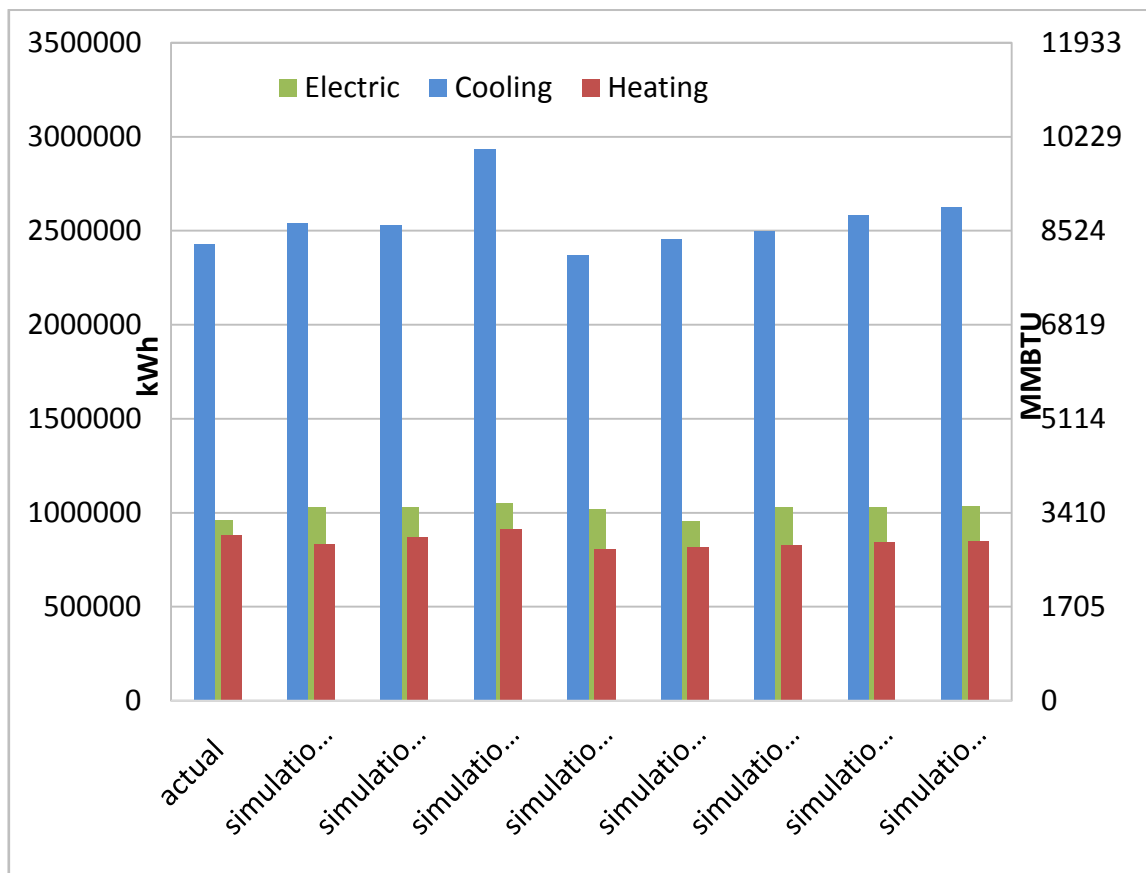


Figure 13. DOE-2 Modeling Results for Eight Occupancy Levels Compared on an Annual Basis to Actual Building Energy Consumption for Langford Building C at Texas A&M University.

A rather surprising result is only at very high occupancy levels did the model start to show an effect from occupancy changes. The limitation of modeling actual human behavior is evident here as the occupancy schedule would almost never be fixed in such a building which would really be the case with most buildings.

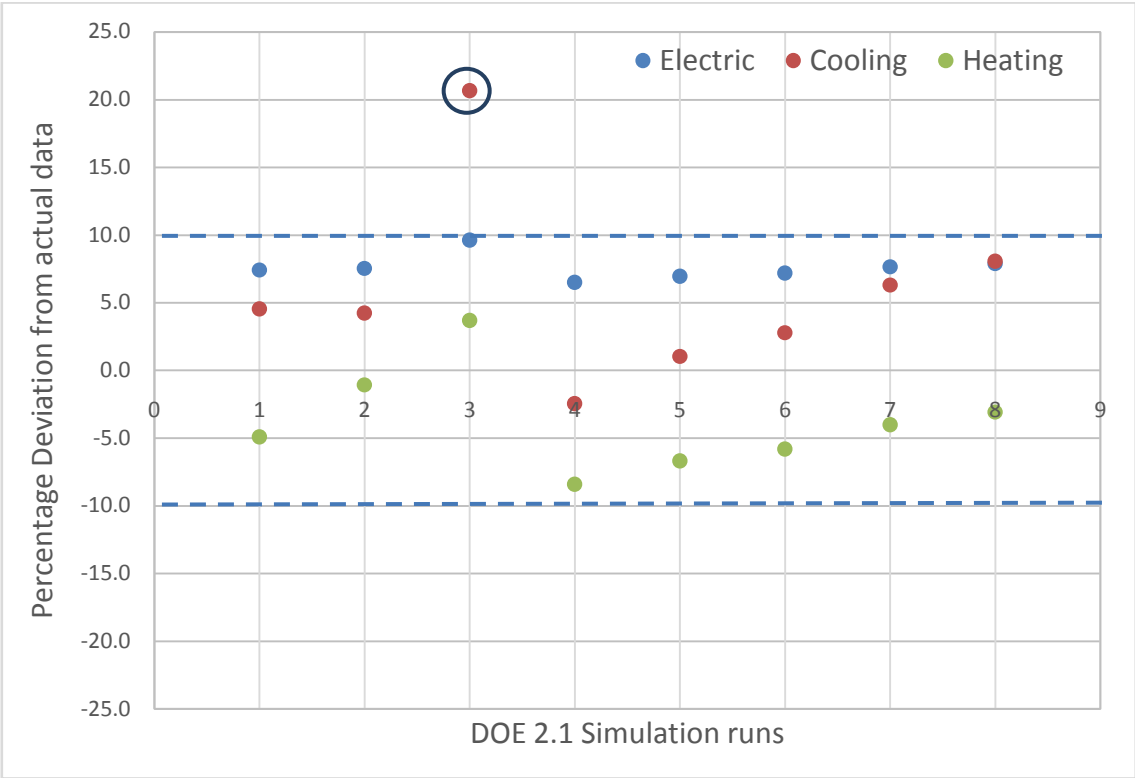


Figure 14. *Percent Deviation from Actual Building Energy Consumption Data for Differing DOE-2 Models.*

A primary driver for this study was to determine if there were significant deviations in the energy model for a building if the actual occupancy level and/or occupancy schedule

were not known. It appears, for the case of this particular university building, that only at an extreme loading (occupancy) level would one expect to see impacts on the annual energy consumption. This is a reassuring result for a designer/energy modeler when performing parametric analysis on a new or existing building. It is shown in this study, that even if the hourly or daily energy profile might not be accurately modeled, that the annual energy consumption will be relatively insensitive (within  $\pm 10\%$ ) to occupancy errors of up to  $\pm 50\%$ .

## 7. CONCLUSIONS

The research provided a better understanding of the sensitivity of building energy simulation tool with occupancy in a typical university classroom building. The results of this research should be of interest to architectural/engineering designers and facility managers involved in the design/construction and operation of an institutional facility. It was observed that the energy simulation tool (DOE-2) was able to generate an energy model to within  $\pm 10\%$  of the actual annual energy consumption data if original occupancy was entered into the model. Even if a designer assumed constant occupancy schedules instead of variable schedules, very little deviation in the annual energy model was observed. Facility managers can depend on the model results if actual occupancy is entered and could use it as a tool to forecast annual energy expenditures for these type buildings and not have to be concerned with high accuracy in occupancy numbers. The results of this work clearly showed that total occupancy or occupancy schedules do not have a significant impact on annual energy use in a university classroom building. As noted earlier, this particular building does not have occupancy sensors on the lighting systems and there are no occupant adjustable thermostats. The lighting systems were observed several times during the study period (Fall and Spring semesters) and lighting was found to be on almost 100% of the time. This building is also not yet converted completely to a direct digital control system for the HVAC equipment and thus, this equipment runs 24 hours, 7 days per week. Even when zero occupancy was modeled, simulated result are still within the range of  $\pm 10\%$  deviation on annual energy use which

shows that there is very little impact of occupancy in this institutional classroom building. As found in the literature review, there is basically no way to model actual human occupant behavior in any type of building. It is possible to model the *results* of behavior; leaving lights on, opening windows, blocking doors open, etc., but these behaviors are not known a priori. Designers, especially, do not have that type of information at hand during the design phase of a building.

The research provides confidence to designers in their energy modeling work. Even if they model a building using an occupancy with a schedule that is 50% higher or lower than what the actual building will support, their error on annual energy performance will not be greater than  $\pm 10\%$ . These results may not be within same confidence level when extended to different kinds of buildings and occupancy. Future work should include extending similar research to different categories of buildings with different types of occupancy and hence differing occupant behavior.

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